

IMAGE PROCESSING APPARATUS, IMAGE PROCESSING METHOD,  
AND RECORDING MEDIUM

BACKGROUND OF THE INVENTION

5 Field of the Invention

The present invention relates to an image processing apparatus and its method for converting a gradation with keeping a high frequency component of an image such as an X-ray image, and a computer-readable storage medium used therefor.

10 Related Background Art

For example, an X-ray chest image is composed of an image of a lung field through which an X-ray is easy to pass and an image of a mediastinum portion through which an X-ray is very hard to pass, and therefore pixel values exist in an extremely wide range. Accordingly it has been considered to be hard to obtain an X-ray chest image on which both of the lung field and the mediastinum portion can be observed simultaneously.

20 Therefore, various methods described below have been conventionally suggested as methods of resolving this problem.

First, there is a method disclosed in SPIE Vol. 626. Medicine XIV/PACSIV (1986). This method is expressed by the following formula (1):

$$S_D = A[S_{ORG} - S_{US} + B(S_{US})] + C \text{ ----- (1)}$$

where  $S_D$  is a pixel value after processing,  $S_{ORG}$  is an original pixel value (input pixel value),  $S_{US}$  is a pixel value of a low frequency image of an original image (input image), and constants A, B, and C (for example, 5 A = 3, B = 0.7).

In this method, it is possible to change weights of a high frequency component (first term) and a low frequency component (second term). For example, if A = 3 and B = 0.7, the high frequency component is 10 highlighted and the entire dynamic range is compressed advantageously. This method is appreciated by five radiotherapists in that the processed image is useful for a diagnosis in comparison with a non-processed image.

15 In addition, there is disclosed a method in Japanese Pat. No. 2509503 which is expressed by the following formula (2):

$$S_D = S_{ORG} + F[G(P_x, P_y)] \text{ ---- (2)}$$

where  $S_D$  is a pixel value after processing,  $S_{ORG}$  is an 20 original pixel value (input pixel value), and  $P_y$  is an average profile in a Y direction profile and  $P_x$  is an average profile in a X direction profile of an original image (input image).

Characteristics of the function  $f(x)$  is described 25 below. First,  $f(0)$  becomes "0" in " $x > D_{th}$ " and  $f(x)$  monotonously decreases with "E" as an intercept and "E/D<sub>th</sub>" as a slope in " $0 \leq x \leq D_{th}$ " as expressed by the

following formula (3):

$$F[x] = E - (E/th)X \text{ ----- (3)}$$

$$P_y = (\sum P_{yi})/n \text{ ----- (4)}$$

$$P_x = (\sum P_{xi})/n \text{ ----- (5)}$$

5 where ( $i = 1 - n$ ),  $P_{yi}$ , and  $P_{xi}$  are profiles. They are expressed by the following formula (6), for example:

$$G = (P_x, P_y) = \max (p_x, p_y) \text{ --- (6)}$$

In this method, a density range of pixel values  $D_{th}$  and lower of a low frequency image is compressed.

10 In addition, as a similar method to the above patent gazette, there is a method referred to as a self-compensatory digital filter in "Self-compensatory Digital Filter," National Cancer Center, Anan et al in Japan Radiation Technical Society Journal Vol. 45,  
15 Issue 8, Aug. 1989, pp. 1,030. This method is expressed by the following formulas (7) and (8):

$$S_d = S_{org} + f(S_{us}) \text{ ----- (7)}$$

$$S_{us} = \sum S_{org}/M^2 \text{ ----- (8)}$$

20 where  $S_d$  is a pixel value after compensation (after processing),  $S_{org}$  is an original pixel value (input pixel value),  $S_{us}$  is an average pixel value of a moving average with a mask size of  $M \times M$  pixels of an original image (input image), and a monotonously decreasing function  $f(X)$  shown in Fig. 35.

25 Next, characteristics of the function  $f(S_{us})$  is described below. First, regarding the characteristics shown in Fig. 35,  $f(S_{us})$  becomes "0" if " $S_{us} > \text{BASE}$ " and

$f(S_{US})$  monotonously decreases with "threshold value  
BASE" as an intercept and SLOPE as a slope if " $0 \leq S_{US} \leq$   
BASE." Therefore when executing the above formula (7)  
with the original pixel value  $S_{ORG}$  as a density  
5 equivalent amount, an effect to an image is obtained  
such as an increase of a density in a range of a lower  
average density of the image.

This method is different from the method expressed  
by the formula (2) in a low frequency image preparing  
10 method; a low frequency image is prepared with two-  
dimensional data in this method while it is prepared  
with one-dimensional data in the formula (2). In this  
method, however, a density range of pixel values Dth  
and lower of the low frequency image is compressed in  
15 the same manner.

Furthermore, there is disclosed a method in  
Japanese Pat. No. 2663189 which is expressed by the  
following formulas (9) and (10):

$$S_D = S_{ORG} + f1(S_{US}) \text{ ----- (9)}$$

20  $S_{US} = \Sigma S_{ORG}/M^2 \text{ ----- (10)}$

where  $f1(X)$  is a monotonously increasing function.

Characteristics of the function  $f1(x)$  is described  
below. First,  $f1(x)$  becomes "0" in " $x < Dth$ " and  $f1(x)$   
monotonously decreases with "E" as an intercept and  
25 "E/Dth" as a slope in " $Dth \leq x$ " as expressed by the  
following formula (11):

$$f1[x] = E - (E/th)X \text{ ----- (11)}$$

Still further, there is disclosed a vivifying method of highlighting a high frequency component of an image having fixed or greater density values in Japanese Pat. No. 1530832. In this method, an  
5 extremely low frequency component is highlighted and a high frequency component having a high occupancy rate of noises is relatively reduced in order to obtain an image easy to see and to improve a diagnostic performance by preventing a false image or an increase  
10 of noises.

There is a method expressed by the following formulas (12) and (13):

$$S_D = S_{ORG} + B(S_{ORG} - S_{US}) \text{ ----- (12)}$$

$$S_{US} = \Sigma S_{ORG}/M^2 \text{ ----- (13)}$$

15 where the constant B is a variable monotonously increasing according to an increase of the  $S_{OR}$  or  $S_{US}$  value. When executing the above formula (12), a high frequency component of an image can be highlighted advantageously.

20 The above method in SPIE Vol. 626. Medicine XIV/PACSIV (1986), however, does not have a concept of compressing a dynamic range of a fixed density range, and therefore a dynamic range of the entire image is equally compressed. Accordingly only a fixed density  
25 range cannot be compressed, by which if this method is used for a lung front image, for example, there is a problem that not only the mediastinum portion but a

density range of a lung portion useful for a diagnosis is compressed and therefore the diagnostic function is degraded in comparison with a method of compressing only the mediastinum portion.

5           The above "self-compensatory digital filter" method has a problem that an unnatural distortion may be generated in a high frequency component unless a form of the above function  $f(S_{US})$  is adapted to decrease to BASE at a fixed ratio (it must be linear).

10          Therefore, it has a problem that a gradation cannot be compressed non-linearly and freely with keeping an amplitude of a high frequency component at an amplitude of a high frequency component of the original image (input image).

15           In addition, generally an image whose dynamic range has been compressed is converted in its gradation again in a CRT display or a film output. The above "self-compensatory digital filter" method or the like does not have a concept of adjusting an amplitude of a  
20          high frequency component of the image after the gradation is converted, and therefore the image whose dynamic range has been compressed is further non-linearly converted in its gradation in a film output and an image display. Accordingly, the conversion  
25          depends upon a slope of a gradation conversion curve and the amplitude of the high frequency component fluctuates. Therefore, it has problems that the

amplitude after the gradation conversion is distorted non-linearly and that the amplitude of a high frequency component becomes low in a range where the gradation conversion curve has a low slope by which an  
5 instructive information disappears even if the dynamic range is compressed with keeping the amplitude of the high frequency component. Furthermore, it has also a problem that an overshoot or an undershoot may occur in an edge portion.

10 Furthermore the above conventional vivifying method of highlighting a high frequency component does not have a concept of compressing the dynamic range while the strength of a high frequency component addition can be freely adjusted, and therefore it has a  
15 problem that an image having a wide range of a density distribution cannot be displayed on a single film sheet.

The present invention is provided to solve these problems and it is an object of the present invention  
20 to freely adjust a range of a density distribution of an image and an amplitude of a high frequency component.

#### SUMMARY OF THE INVENTION

25 It is an object of the present invention to reproduce a noted area favorably.

According to one aspect, the present invention

which achieves this object related to an image processing method including an extracting process of extracting a characteristic amount of an input image, a generating process of generating a high frequency component of the input image, a gradation converting process of converting a gradation of the input image on the basis of the characteristic amount, and an adding process of adding the high frequency component to the input image whose gradation has been converted.

10        It is another object of the present invention to convert a dynamic range according to a medical input image so as to output an image which is effective in a favorable diagnosis.

15        According to another aspect, the present invention which achieves this object relates to an image processing method including an extracting process of extracting a characteristic amount of a medical input image and an output process of outputting the medical image for which a first or a second dynamic range conversion has been performed, having

20        the first dynamic range converting process of converting a dynamic range using a first algorithm on the basis of the characteristic amount and the second dynamic range converting process of converting a

25        dynamic range using a second algorithm on the basis of the characteristic amount.

# BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of an image processing device according to a first embodiment;

Fig. 2 is a characteristic diagram showing a gradation conversion function  $F1()$  according to the first and eight embodiments;

Fig. 3 is a characteristic diagram showing a profile of a smoothed image based on an input image and a morphological filter according to the first embodiment;

Fig. 4 is a characteristic diagram showing a profile of a smoothed image based on a gradation converted image and a morphological filter according to the first and eighth embodiments;

Fig. 5 is a characteristic diagram showing a profile of an input image and a processed image according to the first and eighth embodiments;

Fig. 6 is a characteristic diagram showing a gradation conversion function  $F1()$  according to a second embodiment;

Fig. 7 is a block diagram of an image processing device according to the second embodiment;

Fig. 8 is a characteristic diagram showing a gradation conversion function  $F1()$  according to a third embodiment;

Fig. 9 is a characteristic diagram showing a profile of an input image, a smoothed image of the

input image, and a processed image according to the third embodiment;

Fig. 10 is a block diagram of an image processing device according to the third embodiment;

5 Fig. 11 is a block diagram of an image processing device according to the eighth embodiment;

Fig. 12 is a block diagram of an image processing device according to a ninth embodiment;

10 Fig. 13 is a flowchart of a processing according to the ninth embodiment;

Fig. 14 is a characteristic diagram showing a gradation conversion function  $F1()$  according to the ninth embodiment;

15 Fig. 15 is a characteristic diagram showing a gradation conversion function  $F1()$  according to the ninth embodiment;

Fig. 16 is a block diagram of a constitution of an image processing device according to a tenth embodiment;

20 Fig. 17 is a flowchart of a processing procedure according to the tenth embodiment;

Figs. 18A and 18B are configurational diagrams of an image from which an irradiation area and a passing through area are deleted;

25 Fig. 19 is a characteristic diagram of assistance in explaining the operation of the invention according to the tenth embodiment;

Fig. 20 is a diagram of a constitution of an image processing device according to an 11th embodiment;

Fig. 21 is a flowchart of a processing procedure of a processing according to an 11th embodiment;

5 Fig. 22 is a diagram illustrating an area in which a characteristic amount is extracted;

Fig. 23 is a diagram illustrating a gradation conversion curve of a first gradation converting circuit;

10 Fig. 24 is a diagram illustrating a gradation conversion curve of a second gradation converting circuit;

Fig. 25 is a block diagram of the image processing device according to the 12th embodiment;

15 Fig. 26 is a flowchart of a processing according to the 12th embodiment;

Fig. 27 is a flowchart of a processing of a DRC circuit;

20 Fig. 28 is a characteristic diagram of a density value conversion curve of the DRC circuit;

Fig. 29 is a configurational diagram illustrating an image displayed by a control circuit;

Fig. 30 is a flowchart of a processing of an analysis circuit (1);

25 Fig. 31 is a characteristic diagram of a histogram generated by the analysis circuit (1);

Fig. 32 is a characteristic diagram showing a

gradation conversion curve and a visible density value;

Fig. 33 is a flowchart of a processing of an analysis circuit (2);

Fig. 34 is a characteristic diagram of a profile generated by the analysis circuit (2); and

Fig. 35 is a characteristic diagram showing a monotonously decreasing function used for a conventional dynamic range compression.

## 10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be described below with reference to accompanying drawings.

[First embodiment]

15 A first embodiment is described below, first.

Referring to Fig. 2, there is shown a gradation conversion function  $F1()$  used in the first embodiment. In this diagram, it is assumed that  $f1(x, y)$  is a density value of a two-dimensional input original image,  $f0(x, y)$  is a density value of an output image after a two-dimensional gradation conversion (a converted image), and characters  $x, y$  indicate two-dimensional coordinates. In addition, an abscissa axis is assumed to indicate a density value  $f1(x, y)$  of the input image and an ordinate axis is to indicate a density value  $f0(x, y)$  of the output image (the converted image). In this gradation conversion curve,

a slope (SLOPE) of a 2,500 or lower input density value is 0.2 and a slope of an input density value more than 2,500 is 1.

In Fig. 3, a solid line indicates a profile  $f_1(X)$  of an input image and a dotted line indicates a profile  $f_{us}(X)$  of a smoothed (low frequency) image  $f_{us}(x, y)$ .

In Fig. 4, a solid line indicates a profile  $f_0(X)$  of an image obtained by converting a gradation of the input image based on the gradation conversion curve shown in Fig. 2 and a dotted line indicates a profile  $f_{uso}(X)$  of the smoothed (low frequency) image of the gradation converted image, where  $X$  is a constant.

Referring to Fig. 5, there is shown a result of an image processing method according to this embodiment, in which a solid line indicates a profile  $f_1(X)$  of an input image and a dotted line indicates a profile  $f_d(X)$  of a processed image which has been processed according to this embodiment.

Next, the operation is described.

First, an input image  $f_1(x, y)$  is converted in its gradation with a gradation conversion function  $F_1()$  shown in Fig. 2 as shown in the following formula (14) to obtain an output image  $f_0(x, y)$ :

$$f_0(x, y) = F_1(f_1(x, y)) \text{ ----- (14)}$$

A pixel value  $f_d(x, y)$  of the processed image is obtained on the basis of the following formula (15):

$$f_d(x, y) = f_{uso}(x, y) + F(x, y) \times (f_1(x, y) -$$

$fus(x, y)$  ----- (15)

where  $F(x, y)$  is a function representing a processing effect depending upon coordinates assuming  $F(x, y) = 1$  in this embodiment.

5           In this formula,  $fuso(x, y)$  is a smoothed (low frequency) image of an output image (a converted image)  $f0(x, y)$  and  $fus(x, y)$  is a smoothed (low frequency) image of an input image  $f1(x, y)$ , which are obtained by formulas (16) to (20) described later, for example.

10          Both of an average density and an erosion, dilation, opening, or closing morphological filter can be used for smoothing.

            In the gradation conversion curve  $F1()$  (Fig. 2) used in this embodiment, an amplitude of a high frequency component having a 2,500 or lower density value of the output image  $f0(x, y)$  is compressed to 20 %, while a high frequency component preserves an amplitude of the input image if the density value is more than 2,500 (indicated by a solid line in Fig. 4).

20          The above  $fus(x, y)$  is assumed to be calculated by formulas (16) to (20), supposing that  $f1(x, y)$  is a two-dimensional input original image:

$$f2(x, y) = \min\{f1(x+x1, y+y1) - D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (16)}$$

25            $f3(x, y) = \max\{f2(x+x1, y+y1) + D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (17)}$

$$f4(x, y) = \max\{f3(x+x1, y+y1) + D(x1, y1) | x1 \times x1$$

$$+ y_1 \times y_1 \leq r_1 \times r_1\} \text{----- (18)}$$

$$\text{fus}(x, y) = \min\{f_4(x+x_1, y+y_1) - D(x_1, y_1) | x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \text{----- (19)}$$

where  $D(x, y)$  is a disc filter and  $r_1$  is an arbitrary constant selected according to an input image.

$$D(x, y) = 0, x \times x + y \times y \leq r_1 \times r_1 \\ = -\infty, \text{ etc.} \text{----- (20)}$$

A profile  $\text{fus}(X)$  (indicated by a dotted line in Fig. 3) of the  $\text{fus}(x, y)$  obtained here preserves an edge structure, and it does not cause any overshoots nor undershoots which are disadvantages of the conventional dynamic range compression.

In the same manner,  $\text{fuso}(x, y)$  is assumed to be calculated by formulas (21) to (24), supposing that  $f_0(x, y)$  is an image after a gradation conversion:

$$f_5(x, y) = \min\{f_0(x+x_1, y+y_1) - D(x_1, y_1) | x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \text{----- (21)}$$

$$f_6(x, y) = \max\{f_5(x+x_1, y+y_1) + D(x_1, y_1) | x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \text{----- (22)}$$

$$f_7(x, y) = \max\{f_6(x+x_1, y+y_1) + D(x_1, y_1) | x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \text{----- (23)}$$

$$\text{fuso}(x, y) = \min\{f_8(x+x_1, y+y_1) - D(x_1, y_1) | x_1 \times x_1 + y_1 \times y_1 \leq r_1 \times r_1\} \text{----- (24)}$$

A profile  $\text{fuso}(X)$  (indicated by a dotted line in Fig. 4) of the  $\text{fuso}(x, y)$  obtained here preserves an edge structure, and an intersection point position with  $f_0(X)$  matches an intersection point position of  $\text{fus}(X)$

and  $f_1(X)$ .

A dotted line in Fig. 5 indicates a profile  $fd(X)$  of an obtained processed image  $fd(x, y)$ . The density distribution range of 2,500 or lower density values is compressed to 20 % of the input image and a high frequency component preserves an amplitude of the input image.

Referring to Fig. 1, there is shown a block diagram of a constitution of an image processing device according to this embodiment, which realizes the above formula (15).

In Fig. 1, an input image  $f_1$  is converted in its gradation on the basis of the function in Fig. 2 by a gradation converting unit 101 and a converted image  $f_0$  is obtained. This converted image  $f_0$  is smoothed by a smoothing unit 102 so as to obtain a smoothed image  $f_{us}$  and the obtained image is sent to an addition unit 103.

On the other hand, the above input image  $f_1$  is smoothed by another smoothing unit 104 and a smoothed image  $f_{us}$  is obtained. Next, the smoothed image  $f_{us}$  is subtracted from the input image  $f_1$  by a subtraction unit 105, by which a high frequency component image is obtained. This high frequency component image is subjected to a constant multiplication by a multiplication unit 106 and to an addition to the above smoothed image  $f_{us}$  by the addition unit 103, by which

a processed image  $fd$  is obtained.

As described above, according to the first embodiment, it becomes possible to compress or expand a density distribution range of an arbitrary gradation area of the input image and to adjust freely the amplitude of a high frequency component after the gradation conversion.

[Second embodiment]

A second embodiment is described below.

Referring to Fig. 6, there is shown a gradation conversion function  $F1()$  used for an image processing method according to the second embodiment. In this diagram, it is assumed that  $f1(x, y)$  is a density value of a two-dimensional input original image,  $fus(x, y)$  is a smoothed (low frequency) image of the input image, and  $fus0(x, y)$  is an output image after a gradation conversion (a converted image).

Next, the operation is described.

First, a smoothed image  $fus(x, y)$  of an input image  $f1(x, y)$  is generated by using the formulas (16) to (20), for example and a gradation conversion is performed as shown in the following formula (25) with a gradation conversion function  $F1()$  shown in Fig. 6 to obtain an output image  $fus0(x, y)$ :

$$fus0(x, y) = F1(fus(x, y)) \text{ ----- (25)}$$

A pixel value  $fd(x, y)$  of the processed image is obtained on the basis of the following formula (26):

$$fd(x, y) = fus0(x, y) + F(x, y) \times (f1(x, y) - fus(x, y)) \text{ ---- (26)}$$

where  $F(x, y)$  is a function representing a processing effect depending upon coordinates.

5 Referring to Fig. 7, there is shown a constitution of an image processing device according to this embodiment, which realizes the above formula (26).

10 In Fig. 7, an input image  $f1$  is smoothed by a smoothing unit 201 to obtain a smoothed image  $fus$ , the smoothed image  $fus$  is sent to a subtraction unit 204 and converted in its gradation on the basis of the function in Fig. 6 by a gradation converting unit 202 to obtain a converted image  $fus0$ , and the converted image is sent to an addition unit 203.

15 On the other hand, the above smoothed image  $fus$  is subtracted from the input image  $f1$  by the subtraction unit 204 to obtain a high frequency component image. This high frequency component image is subjected to a constant multiplication by a multiplication unit 205  
20 and to an addition to the above output image  $fus0$  by the addition unit 203, by which a processed image  $fd$  is obtained.

25 As described above, according to the second embodiment, it becomes possible to omit a time for generating a smoothed image after converting a gradation and to reduce a calculation time in comparison with the first embodiment. In addition, it

also possible to compress or expand a density distribution range of an arbitrary gradation area of the input image and to adjust freely the amplitude of the high frequency component after the gradation conversion.

[Third embodiment]

A third embodiment is described below.

Referring to Fig. 8, there is shown a gradation conversion function  $F1()$  used for an image processing method according to the third embodiment. In this diagram, it is assumed that  $f1(x, y)$  is a density value of a two-dimensional input original image,  $f0(x, y)$  is a density value of an output image after a two-dimensional gradation conversion, and characters  $x, y$  indicate two-dimensional coordinates. In addition, an abscissa axis indicates a density value  $f1(x, y)$  of the input image and an ordinate axis indicates a density value  $f0(x, y)$  of the output image.

In Fig. 9, a solid line indicates a profile  $f1(X)$  of an input image, a dotted line indicates a profile  $fus(X)$  of a smoothed (low frequency) image  $fus(x, y)$ , and a long and short dash line indicates a profile  $fd(X)$  of the processed image.

Next, the operation is described.

First, an input image  $f1(x, y)$  is converted in its gradation with a gradation conversion function  $F1()$  shown in Fig. 8 as shown in the following formula (27)

to obtain an output image (a converted image)  $f_0(x, y)$ :

$$f_0(x, y) = F_1(f_1(x, y)) \text{ ----- (27)}$$

A pixel value  $f_d(x, y)$  of the processed image is obtained on the basis of the following formulas (28)

5 and (29):

$$c(x, y) = \partial F_1(f_1(x, y)) / \partial f_1(x, y) \text{ ----- (28)}$$

$$f_d(x, y) = f_0(x, y) + (1 - c(x, y)) \times (f_1(x, y) - f_{us}(x, y)) \text{ ----- (29)}$$

where  $c(x, y)$  is a gradation conversion rate defined by the formula (28).

In this formula,  $f_{us}(x, y)$  is a smoothed (low frequency) image of an input image  $f_1(x, y)$ , which is expressed by a formula (30), for example.

$$f_{us}(x, y) = \frac{\int_{-d}^d \int_{-d}^d f_0(x+x_1, y+y_1) dx_1 dy_1}{\int_{-d}^d \int_{-d}^d dx_1 dy_1} \text{ ----- (30)}$$

15 Any method can be used for the smoothing described above; for example, an erosion, dilation, opening, or closing morphological filter can be used, for example.

Referring to Fig. 10, there is shown a constitution of an image processing device according to this embodiment, which realizes the above formula (29).

20 In Fig. 10, an input image  $f_1$  is converted in its gradation on the basis of the gradation conversion

curve in Fig. 8 by a gradation converting unit 301 to obtain a converted image  $f_0$  and the converted image  $f_0$  is sent to an addition unit 302. On the other hand, the above input image  $f_1$  is smoothed by a smoothing unit 303 and a smoothed image  $f_{us}$  is obtained. The smoothed image  $f_{us}$  is subtracted from the input image  $f_1$  by a subtraction unit 304, by which a high frequency component image is obtained. This high frequency component image is added to the above converted image  $f_0$  by the addition unit 302, by which a processed image  $f_d$  is obtained.

As described above, according to the third embodiment, it becomes possible to compress or expand a density distribution range of an arbitrary gradation area of the input image and to adjust the amplitude of the high frequency component after the gradation conversion so as to be identical to the amplitude of the high frequency component of the input image. In addition, it is also possible to reduce a calculation time since a smoothing processing is required only once. Furthermore, the smoothing method with an average density has an advantage of reducing a calculation time in morphological filter processing.

[Fourth embodiment]

A fourth embodiment is described below.

This embodiment is expressed by an arithmetic expression (31) or (32) with a pixel value  $f_d(x, y)$  of

a processed image, a pixel value  $f_{uso}(x, y)$  of a smoothed image of a first image (an output image after a gradation conversion)  $f_0(x, y)$ , a pixel value  $f_1(x, y)$  of a second image (an input image), a pixel value  
5  $f_{us}(x, y)$  of a smoothed (low frequency) image of the second image, a function  $F()$  for controlling processing effects, and coordinates  $x$  and  $y$  on the image.

$$fd(x, y) = f_{uso}(x, y) + F(f_1(x, y)) \times (f_1(x, y) - f_{us}(x, y)) \text{ ----- (31)}$$

10  $fd(x, y) = f_0(x, y) + F(f_1(x, y)) \times (f_1(x, y) - f_{us}(x, y)) \text{ ----- (32)}$

As described above, according to the fourth embodiment, the function  $F()$  for controlling processing effects depends upon the density value  $f_1(x, y)$  of the  
15 second image, and therefore an amplitude of the high frequency component can be changed according to the density value of the second image.

[Fifth embodiment]

A fifth embodiment is described below.

20 This embodiment is expressed by an arithmetic expression (33) or (34) with a pixel value  $fd(x, y)$  of a processed image, a pixel value  $f_{uso}(x, y)$  of a smoothed image of a first image  $f_0(x, y)$ , a pixel value  $f_1(x, y)$  of a second image, a pixel value  $f_{us}(x, y)$  of  
25 a smoothed (low frequency) image of the second image, a function  $F()$  for controlling processing effects, and coordinates  $x$  and  $y$  on the image.

$$fd(x, y) = fuso(x, y) + F(f0(x, y)) \times (f1(x, y) - fus(x, y)) \text{ ----- (33)}$$

$$fd(x, y) = f0(x, y) + F(f0(x, y)) \times (f1(x, y) - fus(x, y)) \text{ ----- (34)}$$

5           As described above, according to the fifth embodiment, the function  $F()$  for controlling processing effects depends upon the density value  $f0(x, y)$  of the first image, and therefore an amplitude of the high frequency component of a converted image can be changed  
10 according to the density value of the first image.  
[Sixth embodiment]

A sixth embodiment is described below.

This embodiment is expressed by an arithmetic expression (35) or (36) with a pixel value  $fd(x, y)$  of  
15 a processed image, a pixel value  $fuso(x, y)$  of a smoothed image of a first image  $f0(x, y)$ , a pixel value  $f1(x, y)$  of a second image, a pixel value  $fus(x, y)$  of a smoothed (low frequency) image of the second image, a function  $F()$  for controlling processing effects, and  
20 coordinates  $x$  and  $y$  on the image.

$$fd(x, y) = fuso(x, y) + F(fus(x, y)) \times (f1(x, y) - fus(x, y)) \text{ ----- (35)}$$

$$fd(x, y) = f0(x, y) + F(fus(x, y)) \times (f1(x, y) - fus(x, y)) \text{ ----- (36)}$$

25           As described above, according to the sixth embodiment, the function  $F()$  for controlling processing effects depends upon the density value  $fus(x, y)$  of the

smoothed (low frequency) image of the second image, and therefore an amplitude of the high frequency component of a converted image can be changed according to the density value of the smoothed (low frequency) image of the second image. Furthermore, there is no influence of the amplitude of the high frequency component of the second image since the amplitude of the high frequency component is adjusted dependently on the density of the smoothed image.

10 [Seventh embodiment]

A seventh embodiment is described below.

This embodiment is expressed by an arithmetic expression (37) or (38) with a pixel value  $fd(x, y)$  of a processed image, a pixel value  $fuso(x, y)$  of a smoothed image of a first image  $f0(x, y)$ , a pixel value  $fl(x, y)$  of a second image, a pixel value  $fus(x, y)$  of a smoothed (low frequency) image of the second image, a function  $F()$  for controlling processing effects, and coordinates  $x$  and  $y$  on the image.

20 
$$fd(x, y) = fuso(x, y) + F(fuso(x, y)) \times (fl(x, y) - fus(x, y)) \text{ ----- (37)}$$

$$fd(x, y) = f0(x, y) + F(fuso(x, y)) \times (fl(x, y) - fus(x, y)) \text{ ----- (38)}$$

As described above, according to the seventh embodiment, the function  $F()$  for controlling processing effects depends upon the density value  $fuso(x, y)$  of the smoothed (low frequency) image of the first image,

and therefore an amplitude of the high frequency component of a converted image can be changed according to the density value of the smoothed (low frequency) image of the first image. Furthermore, there is no influence of the amplitude of the high frequency component of the first image since the amplitude of the high frequency component is adjusted dependently on the density of the smoothed image.

[Eighth embodiment]

10       Next, the eighth embodiment is described below, with reference to Figs. 2, 4, and 5 used for the first embodiment.

15       In Fig. 2, in the same manner as for the first embodiment,  $f_1(x, y)$  is a density value of a two-dimensional input original image,  $f_0(x, y)$  is a density value of an output image after a two-dimensional gradation conversion, and characters  $x, y$  indicate two-dimensional coordinates. In addition, an abscissa axis indicates a density value  $f_1(x, y)$  of the input image and an ordinate axis indicates a density value  $f_0(x, y)$  of the output image. In this gradation conversion curve, a slope of a 2,500 or lower input density value is 0.2 and a slope of an input density value more than 2,500 is 1.

25       In Fig. 4, a solid line indicates a profile  $f_0(X_9)$  of an output image after the gradation conversion and a dotted line indicates a profile  $f_{uso}(X)$  of a smoothed

(low frequency) image.

In Fig. 5, a solid line indicates a profile  $f1(X)$  of an input image and a dotted line indicates a profile  $fd(X)$  of the processed image as a result of an image processing method according to this embodiment.

Next, the operation is described.

First, an input image  $f1(x, y)$  is converted in its gradation with a gradation conversion function  $F1()$  shown in Fig. 2 as shown in the above formula (14) to obtain an output image  $f0(x, y)$ .

Then, a pixel value  $fd(x, y)$  of the processed image is obtained on the basis of the following formula (39), supposing that  $c(x, y)$  is a function representing a slope of the gradation conversion curve as expressed by the above formula (28):

$$fd(x, y) = fuso(x, y) + a \times (1/c(x, y)) \times (f0(x, y) - fuso(x, y)) \text{ ----- (39)}$$

where  $a$  is a constant and  $fuso(x, y)$  is a pixel value of the smoothed (low frequency) image of the output image  $f0(x, y)$ , expressed by the above formulas (16) to (20).

In the gradation conversion curve  $F1()$  (Fig. 2) used in this embodiment, an amplitude of the high frequency component having a 2,500 or lower density value of the output image (converted image)  $f0(x, y)$  is compressed to 20 %, while the high frequency component preserves an amplitude of the input image if the

density value is more than 2,500 (indicated by a solid line in Fig. 4).

In the same manner as for the first embodiment, both of an average density based on the above formula (30) and the above morphological filter, for example, can be used for the smoothed image.

A profile of the obtained processed image  $fd(x, Y)$  is indicated by a dotted line in Fig. 5. A density distribution range of 2,500 or lower density values is compressed to 20 % and the high frequency component preserves an amplitude of the input image.

Referring to Fig. 11, there is shown a constitution of the image processing device according to this embodiment, which realizes the above formula (39).

In Fig. 11, an input image  $f1$  is converted in its gradation by a gradation converting unit 801 and a converted image  $f0$  is obtained. The converted image  $f0$  is sent to a subtraction unit 805 and smoothed by a smoothing unit 802 to obtain a smoothed image  $fuso$ . The smoothed image  $fuso$  is sent to an addition unit 803.

On the other hand, the subtraction unit 805 subtracts the smoothed image  $fuso$  from the above converted image  $f0$  to obtain a high frequency component. The high frequency component is subjected to a constant multiplication by a multiplication unit

806 and to an addition to the above smoothed image fused by the addition unit 803, by which a processed image is obtained.

As described above, according to the eighth embodiment, it becomes possible to compress or expand a density distribution range of an arbitrary gradation area of the input image and to keep an amplitude of the high frequency component after the gradation conversion at the same amplitude of the high frequency component of the image before the gradation conversion. Furthermore, there are effects that it does not cause any overshoots nor undershoots and that a calculation time is reduced if a density average is used for the smoothed image.

[Ninth embodiment]

Referring to Fig. 12, there is shown a constitution of an image processing device according to a ninth embodiment.

In Fig. 12, there are shown an input image 900 as an original image, a gradation converting unit 901 for converting a gradation of the original image 900, a converted image 902 after the gradation conversion, a fine coefficient storing unit 903 for storing a fine coefficient of a gradation conversion curve used for the gradation converting unit 901, a smoothing image preparation unit 904 for preparing a smoothed image (low frequency image) 905 of the above converted image

902, a high frequency component preparation unit 906 for calculating a difference between the converted image 902 and the smoothed image 905, and a high frequency component adding unit 907 for adding the high frequency component prepared by the high frequency preparation unit 906 to the converted image 902 on the basis of the fine coefficient of the gradation conversion curve stored in the fine coefficient storing unit 903.

Referring to Fig. 13, there is shown a flowchart showing a processing flow of this embodiment. Figs. 14 and 15 show gradation conversion curves used for the gradation converting unit 901, in which an abscissa axis indicates pixel values of an input image and an ordinate axis indicates pixel value of an output image. Fig. 14 shows an S-shaped gradation conversion curve and Fig. 15 shows a curve having slope  $A/B$  for  $B$  or lower input density values and slope 1 for input density values more than  $B$ .

Next, an operation is described below along the processing flow shown in Fig. 13.

The gradation converting unit 901 converts the gradation of the original image 900 on the basis of the gradation conversion curves shown in Figs. 14 and 15, for example, as expressed by a formula (40) (Step S201). In this formula,  $f_1(x, y)$  is a density value of the two-dimensional input original image 900,  $f_0(x, y)$

is a density value of the two-dimensional converted image 902 after the gradation conversion, and  $F1()$  is the gradation conversion curve. Characters  $x, y$  indicate two-dimensional coordinates.

5 
$$f0(x, y) = F1(f1(x, y)) \text{ ---- (40)}$$

The fine coefficient storing unit 903 calculates a fine coefficient of the gradation conversion curve expressed by a formula (41) and stores the density value as a table  $c(x)$  (S202).

10 A 
$$\overset{c(x)}{\underset{\wedge}{c(F1(x))}} = 1 - [\partial F1(x) / \partial x] \text{ ----- (41)}$$

Next, in the smoothing image preparation unit 904, the smoothed image 905 is calculated from the image 902 on the basis of the above formula (30) (S203).

Subsequently, the high frequency component preparation unit 906 calculates a high frequency image from the gradation converted image 902 and the smoothed image 905 as expressed by the formula (42) (S204):

15 
$$fh(x, y) = f0(x, y) - fus(x, y) \text{ ---- (42)}$$

where  $fh(x, y)$  is a pixel value of a high frequency image.

20

The high frequency component adding unit 907 adds the high frequency component calculated by the high frequency component preparation unit 906 to the converted image 902 after the gradation conversion on the basis of the fine coefficient stored by the fine coefficient storing unit 903 as expressed by the following formula (43) to obtain a processed image

25

fd(x, y) (S205):

$$fd(x, y) = f0(x, y) + a \times c (f0(x, y)) \times fh(x, y)$$

---- (43)

where a is a constant.

5           The smoothed image 905 can also be calculated with  
the above formulas (16) to (20) by using a  
morphological operation.

10           The obtained profile of fus(x, y) preserves an  
edge structure and does not cause overshoots nor  
undershoots which are disadvantages of the conventional  
dynamic range compression.

15           According to this embodiment, it becomes possible  
to compress or expand a density distribution range of  
an arbitrary gradation area of the input image and to  
keep the amplitude of the high frequency component  
after the gradation conversion at the same amplitude of  
the high frequency component of the image before the  
gradation conversion. Furthermore, there are effects  
that it does not cause any overshoots nor undershoots  
20           and that a calculation time is reduced if a density  
average is used for the smoothed image.

[Tenth embodiment]

A tenth embodiment will be described below by  
using accompanying drawings.

25           Referring to Fig. 16, there is shown an image  
processing device 1100 according to this embodiment of  
the invention.

The image processing device 1100 is an image processing device of an X-ray image having a density value converting function, comprising a pre-process circuit 1106, a density value converting unit 1113, a CPU 1108, a main memory 1109, an operation panel, and an image display device 1111, among which data is sent or received each other via a CPU bus 1107.

In addition, the image processing device 1100 has a data collecting circuit 1105 connected to the pre-process circuit 1106 and a two-dimensional X-ray sensor 1104 and an X-ray generating circuit 1101 connected to the data collecting circuit 1105, and these circuits are also connected to the CPU bus 1107.

Referring to Fig. 2, there is shown a flowchart showing a processing flow of the image processing device.

Fig. 18A shows an input image and Fig. 18B is a diagram as a result of deleting an X-ray irradiation area and a passing through area (an area through which an X-ray has passed) from the input image.

Fig. 19 is a diagram showing a relationship between a density area which is visible on a gradation conversion curve and a density area of a noted area, in which an abscissa axis indicates density values of an input image and an ordinate axis indicates density values of an output image.

In the image processing device 1100 having the

above constitution, the main memory 1109 is used to store various data required for processing of the CPU 1108 and contains a work memory for works of the CPU 1108. The CPU 1108 controls an operation of the entire device following an operation from the operation panel 1110 by using the main memory 1109. Accordingly, the image processing device 1100 operates as described below.

First, an examined object 1103 is irradiated with an X-ray beam 1102 from the X-ray generating circuit 1101. The X-ray beam 1102 passes through the examined object 1103 with being damped and reaches the two-dimensional X-ray sensor 1104 to be output as an X-ray image from the two-dimensional X-ray sensor 1104. In this embodiment, the X-ray image output from the two-dimensional X-ray sensor 1104 is assumed to be a knee or thoracic vertebra image as shown in Fig. 18A, for example.

The data collecting circuit 1105 converts the X-ray image output from the two-dimensional X-ray sensor 1104 to electric signals to supply them to the pre-process circuit 1106. The pre-process circuit 1106 performs preprocessing such as offset correcting processing or gain correcting processing for the signals (X-ray image signals) from the data collecting circuit 1105. The pre-processed X-ray image signals are transferred as an input image to the main memory

1109, an irradiation area extracting circuit 1112, and a passing through deleting circuit 1113a of the density value converting unit 1113 via the CPU bus 1107 under a control of the CPU 1108.

5           In the density value converting unit 1113, there are the passing through deleting circuit 1113a for deleting a passing through area and a body area in contact with the passing through area within a fixed space, a maximum/minimum value extracting circuit 1113b  
10           for calculating the maximum and minimum values of the density value from an area which has not been deleted by the passing through deleting circuit 1113a, a smoothing image preparing circuit 1113c for preparing a smoothed image of the input image, a high frequency  
15           component preparing circuit 1113d for preparing a high frequency component on the basis of the difference between the input image and the smoothed image, a density value converting circuit 1113e for converting  
20           the density value of the smoothed image on the basis of the maximum and minimum values extracted by the maximum/minimum value extracting circuit 1113b, and a high frequency component adding circuit 1113f for  
25           adding the high frequency component prepared by the high frequency component preparing circuit 1113d to the image converted by the density value converting circuit 1113e.

Subsequently, the operation of the density value

converting unit 1113 is described below by using the flowchart in Fig. 17.

The irradiation area extracting circuit 1112 receives an input image processed by the pre-process circuit 1106 via the CPU bus 1107 under the control of the CPU 1108 and extracts an irradiation area in the input image (Step S1201). On the other hand, the passing through deleting circuit 1113a which has received the input image replaces a passing through area outside and inside the irradiation area and a body area which is in contact with the passing through area within a fixed space with 0 pixels, for example (Step S1202). Specifically, the image is converted as follows.

7360 15 
$$f1(x,y) = f(x,y) \times \prod_{x1=-d1}^{x1=d1} \prod_{y1=-d2}^{y1=d2} \text{sgn}(x+x1,y+y1) \text{ ---- (112)}$$

where  $f(x, y)$  is image data and  $f1(x, y)$  is an image as a result of deleting the passing through area and the body area in contact with the passing through area within a fixed space.  $\text{Sgn}(x, y)$  is expressed by the following formula (113):

20 
$$\begin{aligned} \text{If } \text{sgn}(x, y) &= 0 \text{ and } f(x, y) \geq \text{Th1}, \\ \text{sgn}(x, y) &= 1, \text{ etc. --- (113)} \end{aligned}$$

where  $\text{Th1}$  is a constant determined by an experiment and  $d1$  and  $d2$  are constants for determining a width by which a body area is deleted.

25 Fig. 18B shows an image obtained by replacing an

area outside the irradiation area of the input image and the passing through area with zero (0).

Next, the maximum/minimum value extracting circuit 1113b calculates the maximum value (d2 in Fig. 19) and the minimum value (d3 in Fig. 19) of the image density value (Step S1203). In calculating the maximum value and the minimum value, the values can also be extracted from the smoothed image of an area after the irradiation area and the passing through area are deleted. Subsequently the smoothing image preparing circuit 1113c prepares a smoothed image on the basis of the following formula (Step S1204), supposing that  $fus(x, y)$  is a pixel value of a smoothed (low frequency) image of the input image  $f0(x, y)$ , which is expressed by the formulas (114) to (118) or a formula (119), for example:

$$f2(x, y) = \min\{f0(x+x1, y+y1) - D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (114)}$$

$$f3(x, y) = \max\{f2(x+x1, y+y1) + D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (115)}$$

$$f4(x, y) = \max\{f3(x+x1, y+y1) + D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (116)}$$

$$fus(x, y) = \min\{f4(x+x1, y+y1) - D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (117)}$$

where  $D(x, y)$  indicates a disc filter and  $r1$  indicates an arbitrary constant, selected according to the input image.

$$D(x, y) = 0, x \times x + y \times y \leq r1 \times r1 \\ = -\infty, \text{ etc. } \text{----} (118)$$

5 A profile of  $fus(x, y)$  obtained here preserves an edge structure, by which it does not cause overshoots nor undershoots which are disadvantages of the conventional dynamic range compression.

For the smoothed image, it is possible to use both of an average density expressed by the formula (117), for example, and the following formula:

10  $fus(x, y) = \frac{\int_{-d}^d \int_{-d}^d f1(x+x1, y+y1) dx1 dy1}{\int_{-d}^d \int_{-d}^d dx1 dy1} \text{-----} (119)$

where  $d$  indicates a constant.

In addition, it is also possible to prepare a smoothed image by using an erosion, dilation, opening, or closing morphological filter, for example.

15 Subsequently, the high frequency component preparing circuit 1113c prepares a high frequency image  $fh(x, y)$  on the basis of the formula described below from the input image  $f0(x, y)$  and the smoothed image  $fus(x, y)$  (Step S205). Then, the density value  
20 converting circuit 1113e converts the density value by the formula described below on the basis of the maximum value ( $d3$ ) and the minimum value ( $d2$ ) extracted by the

maximum/minimum value extracting circuit 1113b and density values d1 and d4 determined by a visible density value after a gradation conversion to prepare a smoothed image  $Sus0 \times (x, y)$  as a result of converting the density value (Step S1206).

In Fig. 19, Sightmax and Sightmin indicate the visible maximum and minimum density values corresponding to d4 and d1, respectively. If the density value of the smoothed image is within a range of min (the minimum value which can be obtained in the smoothed image) to d1,

$$Susu0(x, y) = (d1 - min) \times ((Sus(x, y)) - min) / (d2 - min) + min \text{ ----- (120)}$$

If  $d2 < Sus(x, y) \leq d3$ ,

$$Susu0(x, y) = (d4 - d1) \times (Sus(x, y) - d2) / (d3 - d2) + d1 \text{ ----- (121)}$$

If  $d3 < Sus(x, y) \leq max$ ,

$$Susu0(x, y) = (max - d4) \times (Sus(x, y) - d3) / (max - d3) + d4 \text{ ----- (122)}$$

Then, the high frequency image  $fh(x, y)$  is added to the density-value converted image  $Susu0(x, y)$  to obtain a final image  $fe(x, y)$  (Step S1207).

$$fe(x, y) = Susu0(x, y) + fh(x, y) \text{ ----- (123)}$$

Finally, the obtained image  $fe(x, y)$  is converted in its gradation by the gradation converting circuit 1114 and it is output as a film output or displayed on an image display device 1111.

Although an operation for an image having a passing through area has been described in this embodiment, the maximum value and the minimum value can be extracted by the maximum/minimum value extracting circuit 1113b from an image within an irradiation area bypassing the passing through deleting circuit 1113a if there is no passing through area.

According to this embodiment, it is possible to compress or expand an image in a noted area to a fixed range with preserving a high frequency component and to use image information effectively. Furthermore, assuming that the above fixed range is a visible area on a film, a noted area can be expanded or compressed to a size of the visible area on the film. In addition, in extracting the maximum value or the minimum value from a smoothed image, there is an effect that the conversion with the density value converting unit 1113 can be performed more precisely.

[Eleventh embodiment]

Referring to Fig. 20, there is shown a constitution of an X-ray phototaking device 1600 to which an image processing device is applied according to an Eleventh embodiment. The X-ray phototaking device 1600, which has an image processing function, comprises a pre-process circuit 1606, a CPU 1608, a main memory 1609, an operation panel 1610, an image display device 1611, and an image processing circuit

1612, among which data is sent or received each other via a CPU bus 1607.

In addition, the image processing device 1600 has a data collecting circuit 1605 connected to the pre-  
5 process circuit 1606 and a two-dimensional X-ray sensor 1604 and an X-ray generating circuit 1601 connected to the data collecting circuit 1605, and these circuits are also connected to the CPU bus 1607.

In this diagram, there are a characteristic  
10 extracting circuit 1612a for calculating a characteristic amount for a gradation conversion, a control circuit 1612b for calculating a range and a change amount of changing a dynamic range on the basis of a gradation conversion curve of a first gradation  
15 converting circuit, and a DRC circuit 1612c for changing a dynamic range of an original image on the basis of the range and the change amount of changing the dynamic range calculated by the control circuit 1612b. The DRC circuit 1612c comprises a second  
20 gradation converting circuit 1613 for converting a gradation of the original image and a high frequency component adjusting circuit for adding a high frequency component of the original image to the image whose gradation has been converted by the second gradation  
25 converting circuit 1613. A first gradation converting circuit 1612d converts a gradation of the original image whose dynamic range has been changed by the DRC

circuit 1612c.

Referring to Fig. 22, there is shown a diagram illustrating an area from which a characteristic is extracted when phototaking the side of cervical  
5 vertebrae, for example.

Referring to Fig. 23, there is shown a gradation conversion curve of the first gradation converting circuit 1612d, in which an abscissa axis indicates pixel values and an ordinate axis indicates density  
10 values. In addition, reference character S1 indicates a pixel value corresponding to a lower limit density value of a visibility limit on a density, reference character Sh indicates a pixel value corresponding to an upper limit density value of the visibility limit on  
15 the density, reference characters Smin and Smax indicate the minimum pixel value and the maximum pixel value of a noted area, reference character Sa indicates a pixel value corresponding to a characteristic amount calculated by the characteristic extracting circuit  
20 1612a, and reference characters dl and dh indicate pixel values corresponding to a lower limit density value and an upper limit density value of a range which is not subjected to a change of the dynamic range, respectively.

25 Referring to Fig. 24, there is shown a gradation conversion curve of the second gradation converting circuit 1613, in which an abscissa axis indicates input

pixel values, an ordinate axis indicates output pixel values, and dl, dh, and Sa indicate the above pixel values. A gradation conversion curve a is formed only by linear components, while a gradation conversion  
5 curve b is formed by a smooth curve so as to obtain continuous differential values of the gradation conversion curve a.

In the above X-ray phototaking device, first the main memory 1609 is used to store various data required  
10 for processing in the CPU 1608 and contains a work memory for works of the CPU 1608.

The CPU 1608 controls an operation of the entire device following an operation from the operation panel 1610 by using the main memory 1609. Accordingly, the  
15 X-ray phototaking device 1600 operates as described below.

First, an examined object 1603 is irradiated with an X-ray beam 1602 from an X-ray generating circuit 1601. The X-ray beam 1602 from the X-ray generating  
20 circuit 1601 passes through the examined object 1603 with being damped and reaches the two-dimensional X-ray sensor 1604 to be output as an X-ray image from the two-dimensional X-ray sensor 1604. The X-ray image output from the two-dimensional X-ray sensor 1604 is an  
25 image of a human body, for example.

The data collecting circuit 1605 converts the X-ray image output from the two-dimensional X-ray sensor

1604 to electric signals to supply them to the pre-process circuit 1606. The pre-process circuit 1606 performs preprocessing such as offset correcting processing or gain correcting processing for the signals (X-ray image signals) from the data collecting circuit 1605. The X-ray image signals pre-processed by the pre-process circuit 1606 are transferred as an input image to the main memory 1609 and an image processing circuit 1612 via the CPU bus 1607 under a control of the CPU 1608.

Next, the operation of the image processing circuit 1612 is described below following the processing flowchart in Fig. 21.

The characteristic extracting circuit 1612a receives an original image  $f_0(x, y)$  processed by the pre-process circuit 1606 via the CPU bus 1607 under the control of the CPU 1608 and calculates a characteristic amount  $S_a$  for a gradation conversion (S1701). This characteristic amount calculation method depends upon a region, and a plurality of methods are also applied by an applicant of this invention. In phototaking an image of cervical vertebrae, for example, a method disclosed in the Japanese Patent Application No. 10-272284 is used. In this method, depression information of a neck is used as a characteristic amount  $S_a$  to calculate an average value of pixel values from an area  $a$  shown in Fig. 22.

Subsequently, a gradation conversion curve with the first gradation converting circuit 1612d is defined by using the characteristic amount Sa. As shown in Fig. 23, for example, a gradation conversion curve is defined so that the pixel value of the characteristic amount Sa is changed to that of a density value 1.0.

Next, the control circuit 1612b calculates a range and a change amount of changing a dynamic range of an original image on the basis of the above defined gradation conversion curve (S1703).

The method is described specifically below. For example, an ordinary Japanese is visible in a range of density values 0.2 to 3.0. On the basis of the above gradation conversion curve, a calculation is made for the pixel values Sl and Sh which are to be converted in the gradation to density values 0.2 and 3.0, respectively. Subsequently, a range in which a dynamic range is not changed is calculated on the basis of the following formulas (124) and (125):

$$dl = Sa - hl \text{ ----- (124)}$$

$$dh = Sa + hh \text{ ----- (125)}$$

where hl and hh indicate constants and dl and dh indicate pixel values to be a starting point of changing the dynamic range. Next, a change amount Rl and Rh for dl and lower pixel values and for pixel values greater than dl are calculated on the basis of the following formulas (126) and (127), respectively:

$$R_l = (S_l - d_l) / (S_{min} - d_l) \text{ ----- (126)}$$

$$R_h = (S_h - d_h) / (S_{max} - d_h) \text{ ----- (127)}$$

where  $S_{min}$  and  $S_{max}$  indicate the minimum and maximum values among pixel values in the area of an object for photographing (noted area), respectively. In other words, if a dynamic range of  $d_l$  and lower pixel values is multiplied by  $R_l$ , the pixel value  $S_{min}$  is changed to the pixel value  $S_l$ . In the same manner, the pixel value  $S_{max}$  is changed to the pixel value  $S_h$ . In other words, supposing that the starting point is  $d_l$  and  $d_h$  and that a change amount is  $R_l$  and  $R_h$ , the density value of the area of an object for photographing after a gradation conversion matches a range of a visible area (a range of the density values 0.2 to 3.0 in the above).

As described above, all of the noted area of the photographed image can be reproduced on an output image by obtaining the values  $R_l$  and  $R_h$  even if the dynamic range is compressed. Accordingly, an instability in extracting characteristics can be absorbed, by which a diagnostic performance can be improved.

In addition, restrictive conditions can be applied to the change amounts  $R_l$  and  $R_h$  as expressed by the following formulas (128) and (129):

$$R_l < C_l \text{ ----- (128)}$$

$$R_h < C_h \text{ ----- (129)}$$

where  $C_l$  and  $C_h$  are constants. Values  $C_l$ ,  $C_h$ ,  $h_l$ , and

hh are experimentally determined for each region to be photographed.

By providing the restrictive conditions in this manner, an excessive compression can be prevented, by which a diagnostic performance can be prevented from being lowered by the excessive compression.

Subsequently, a gradation conversion curve of the second gradation converting circuit 1713 is prepared as shown in Fig. 24 on the basis of the  $d_l$ ,  $d_h$ ,  $R_l$ , and  $R_h$  calculated by the control circuit 1712b. A slope of  $d_l$  and lower pixel values on the gradation conversion curve a is equal to  $R_l$ , a slope in a range of pixel values  $d_l$  to  $d_h$  is equal to 1, and a slope of pixel values greater than  $d_h$  is equal to  $R_h$ . A gradation conversion curve b is smoothed so as to obtain continuous differential values of the gradation conversion curve a (for example, Japanese Patent Application No. 11-76882 to Shinbata is used). If the gradation conversion curve a is used, a false outline may be generated at discontinuous differential points. If the gradation conversion curve b is used, however, no false outline is generated. In this embodiment, a description will be made below for an operation in using the gradation conversion curve b.

The DRC circuit 1712c selects whether or not the high frequency component is preserved (S1704).

Processing without preserving the high frequency

component is effective for diagnosing stem tissues in which a low frequency component is important.

Processing with preserving the high frequency component is effective for diagnosing a bone portion or  
5 a lung field in which the high frequency component is important.

The processing selection in S1704 can be performed by an automatic selection on the basis of the photographed region and also can be performed by a  
10 manual selection by a user in view of the above characteristics.

Unless the high frequency component is preserved, an original image is converted in the gradation by using the gradation conversion curve b by the second  
15 gradation conversion circuit 1713 (S1708). The image after the gradation conversion is converted in the gradation by the first gradation converting circuit 1612d (S1709). Supposing that x and y are coordinates of the original image,  $f_0(x, y)$  indicates a pixel value  
20 of the original image,  $F(x)$  indicates a gradation conversion curve b,  $f_1(x, y)$  indicates a pixel value after the gradation conversion based on the gradation conversion curve b, and  $F_1(x)$  indicates a gradation conversion curve of the first gradation converting  
25 circuit 1612d, a final image  $f_2(x, y)$  is expressed by the following formula (130):

$$f_2(x, y) = F_1(F(f_0(x, y))) \text{ ----- (130)}$$

where  $F1(F(x))$  is considered to be a single gradation conversion curve.

Next, a calculation is described below for preserving the high frequency component. First, a high frequency component  $fh(x, y)$  of the original image is calculated on the basis of the following formula (131) by the high frequency component adjusting circuit 1614, with the smoothed image  $fus(x, y)$  being calculated on the basis of the formula (132):

10  $fh(x, y) = f0(x, y) - fus(x, y) \text{ ----- (131)}$

where  $d$  is a constant indicating a mask size.

$$fus(x, y) = \frac{\int_{-d}^d \int_{-d}^d f0(x+x1, y+y1) dx1 dy1}{\int_{-d}^d \int_{-d}^d dx1 dy1} \text{ ----- (132)}$$

Then, the second gradation converting circuit 1613 performs a gradation conversion expressed by the

15 following formula (133):

$$f1(x, y) = F(f0(x, y)) \text{ ----- (133)}$$

Subsequently, the high frequency component adjusting circuit 1614 calculates a coefficient  $c(x)$  from a fine coefficient of the gradation conversion curve  $b$  used by the second gradation converting circuit 1613 on the basis of the following formula (134), supposing that the coefficient  $c(x)$  is a value equal to

1 minus a slope of the gradation conversion curve:

$$c(x) = 1 - \frac{\partial F(x)}{\partial x} \text{ ----- (134)}$$

Then, the high frequency component adjusting circuit 1614 adds the high frequency component  $h(x, y)$  to the image  $f1(x, y)$  on the basis of the coefficient  $c(x)$  as expressed by the following formula (135) to obtain a processed image  $f3(x, y)$  (S1707):

$$f3(x, y) = f1(x, y) + c(f0(x, y)) \times fh(x, y) \text{ ----- (135)}$$

Subsequently, the first gradation converting circuit 1612d performs a gradation conversion on the basis of the following formula (136) to obtain an image  $f28(x, y)$  (S1709):

$$f2(x, y) = F1(f3(x, y)) \text{ ----- (136)}$$

A smoothed image  $fus(x, y)$  can be calculated by a morphological operation as expressed by the following formulas (137) to (141):

$$f2(x, y) = \min\{f0(x+x1, y+y1) - D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (137)}$$

$$f3(x, y) = \max\{f2(x+x1, y+y1) + D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (138)}$$

$$f4(x, y) = \max\{f3(x+x1, y+y1) + D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (139)}$$

$$fus(x, y) = \min\{f4(x+x1, y+y1) - D(x1, y1) | x1 \times x1 + y1 \times y1 \leq r1 \times r1\} \text{ ----- (140)}$$

where  $D(x, y)$  is a disc filter and  $r1$  is an arbitrary

constant, selected according to an input image.

$$\begin{aligned} D(x, y) &= 0, \quad x \times x + y \times y \leq r1 \times r1 \\ &= -\infty, \text{ etc.} \quad \text{----- (141)} \end{aligned}$$

5 A profile of  $fus(x, y)$  obtained here preserves an edge structure, by which it does not cause overshoot nor undershoots which are disadvantages of the conventional dynamic range compression.

10 According to this embodiment, it becomes possible to compress or expand a density distribution range of an arbitrary gradation area of the input image and to keep an amplitude of the high frequency component after the gradation conversion at the same amplitude of the high frequency component of the image before the gradation conversion. Furthermore, a dynamic range of  
15 the image is changed on the basis of the pixel value determined by the gradation conversion curve, and therefore the dynamic range can be changed assuming a density value of the image after the gradation conversion, by which a range of the density value after  
20 the gradation conversion can be adjusted uniquely.

In addition, a pixel value depending upon a visibility limit is obtained from the gradation conversion curve and a range and an amount of changing the dynamic range can be determined based on the pixel  
25 value, and therefore a range of the density value of the pixel value in the noted area can be put within the visible range. Furthermore, the noted area exists in a

visible area, and therefore the entire noted area can be observed, by which a diagnostic performance is increased. Still further, the noted area can be matched with the range of the visible area, by which an information amount of the noted area can be expanded to the maximum as a density value. There is provided a range in which the dynamic range of the image is not changed, and therefore assuming a pixel range important for a diagnosis to be an area in which the dynamic range is not changed, it is represented with density values in the conventional manner and an area which has been invisible conventionally can also be observed with density values, by which the diagnostic performance is increased.

Furthermore, the high frequency component is preserved by the dynamic range changing unit, and therefore an information amount of the high frequency component is not decreased and further it becomes possible to observe density values of an area which have been invisible on the density values, by which the diagnostic performance is increased.

[Twelfth embodiment]

Referring to Fig. 25, there is shown a constitution of an image processing device 2100 according to a Twelfth embodiment.

The image processing device 2100, which is an X-ray image processing device having a density value

converting function, comprises a pre-process circuit 2106, a density value converting circuit 2113, a CPU 2108, a main memory 2109, an operation panel 2110, and an image display device 2111, among which data is sent or received each other via a CPU bus 2107.

The image processing device 2100 also comprises a data collecting circuit 2105 connected to the pre-process circuit 2106 and a two-dimensional X-ray sensor 2104 and an X-ray generating circuit 2101 connected to the data collecting circuit 2105. These circuits are also connected to the CPU bus 2107.

The density value converting circuit 2113 comprises a passing through deleting circuit 2113a, analysis circuits (1) to (n) 2113b to 2113e, a DRC circuit 2113f, and a control circuit 2113g.

Referring to Fig. 26, there is shown a flowchart showing a processing flow of the image processing device according to this embodiment. Fig. 27 shows a flowchart of a processing flow of the dynamic range compression (DRC) circuit and Fig. 28 shows a density value conversion curve used for the DRC circuit.

Referring to Fig. 29, there is shown a screen displayed on the image display device 2111 by the control circuit, in which a density value conversion curve 2501 is determined by parameters of DRC processing. Diagram 2502 shows an input image or a DRC-processed image and density starting points for the

DRC processing; for example, triangles indicate compression density starting points in a low density side and cross marks indicate compression density starting points in a high density side. When using a color monitor, the starting point density values are changed in red or blue. Reference numeral 2510 indicates a changing unit for changing parameters for the DRC processing, having parameter change buttons 2503 to 2506. There are a button 2503 for changing a compression starting point in the low density side, a button 2504 for changing a compression rate in the low density side, a button 2505 for changing a compression starting point in the high density side, and a button 2506 for changing a compression rate in the high density side.

Fig. 30 shows a flowchart of a processing flow of the above analysis circuit (1) and Fig. 31 shows a diagram of a histogram and a characteristic amount generated by the analysis circuit (1). Figs. 32, 33, and 34 show a diagram illustrating a relationship between a gradation conversion curve and a visible density value, a flowchart of a processing of an analysis circuit (2), and a diagram illustrating a relationship between a profile generated by the analysis circuit (2) and a characteristic amount, respectively.

Next, an operation of the image processing device

2100 having the above constitution is described below.

The main memory 2109 is used to store various data required for processing of the CPU 2108 and contains a work memory for works of the CPU 2108. The CPU 2108  
5 controls the entire operation of the device following an operation from the operation panel 2110 by using the main memory 2109. Accordingly, the image processing device 2100 operates as described below.

First, an examined object 2103 is irradiated with  
10 an X-ray beam 2102 from the X-ray generating circuit 2101. The emitted X-ray beam 2102 passes through the examined object 2103 with being damped and reaches the two-dimensional X-ray sensor 2104 to be output as an X-ray image from the two-dimensional X-ray sensor 2104.  
15 In this embodiment, the X-ray image output from the two-dimensional X-ray sensor 2104 is assumed to be an image of a chest, limbs including a knee, and thoracic vertebra, for example.

The data collecting circuit 2105 converts the X-  
20 ray image output from the two-dimensional X-ray sensor 2104 to electric signals to supply them to the pre-process circuit 2106. The pre-process circuit 2106 performs preprocessing such as offset correcting processing or gain correcting processing for the  
25 signals (X-ray image signals) from the data collecting circuit 2105. The pre-processed X-ray image signals are transferred as an input image to the main memory

2109, an irradiation area extracting circuit 2112, and a passing through deleting circuit 2113a of the density value converting circuit 2113 via the CPU bus 2107 under a control of the CPU 2108.

5           In the density value converting circuit 2113, there are the passing through deleting circuit 2113a for deleting a passing through area of the image (an area through which the X-ray passes) and a body area in contact with the passing through area within a fixed  
10   space, an analysis circuit (1) 2113b for calculating parameters for the DRC processing from areas which have not been deleted by the passing through deleting circuit 2113a for coping with an image of limbs or the like, an analysis circuit (2) 2113c for calculating the  
15   parameters for the DRC processing from the areas which have not been deleted by the passing through deleting circuit 2113a for coping with an image of hands and feet or the like, an analysis circuit (3) 2113d for calculating the parameters for the DRC processing from  
20   the areas which have not been deleted by the passing through deleting circuit 2113a for coping with an image of a front view of lungs, and an analysis circuit (n) 2113e for calculating the parameters for the DRC processing for coping with an image of other regions,  
25   indicating a plurality of analysis circuits in this embodiment.

The DRC circuit 2113f performs the DRC processing

for an input image. The control circuit 2113g controls the operation to display an image subjected to the DRC processing by the DRC circuit 2113f and the parameters for the DRC processing on the image display device 2111.

The gradation converting circuit 2114 converts the DRC-processed image in the gradation for a printer (not shown) or the image display device 2111.

Subsequently, the operation of the density value converting circuit 2113 is described below by using the flowchart in Fig. 26.

First, on the basis of an input from the operation panel 2110, it is selected whether the parameters for the DRC processing are automatically calculated by using the analysis circuits 2113a to 2113e or manually input by using the changing unit 2510 (S2201).

Then, the processing for a selection of the manual input is described below.

A predetermined parameter for the DRC processing is input in the DRC circuit 2113f and the input image is subjected to the DRC processing. The DRC processing flow is described below by using Fig. 27.

First, the DRC circuit 2113f receives an input image  $f(x, y)$  from the pre-process circuit 2106 or the main memory 2109 and calculates a smoothed image  $Sus(x, y)$  on the basis of the following formula (Step S2301):

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$$Sus(x, y) = \frac{\int_{-d1}^{d1} \int_{-d2}^{d2} f(x+x1, y+y1) dx1 dy1}{\int_{-d1}^{d1} \int_{-d2}^{d2} dx1 dy1} \text{ ----- (203)}$$

Then, the smoothed image  $Sus(x, y)$  is stored in the main memory 2209 until it receives an end signal from the CPU 2208 (Step S2302). Next, a high frequency component  $fh(x, y)$  is prepared with the following formula (Step S2303):

$$fh(x, y) = f(x, y) - S_{us}(x, y) \text{ ----- (204)}$$

Subsequently, the high frequency component  $fh(x, y)$  is stored in the main memory 2209 until it receives an end signal from the CPU 2208 (Step S2304).

Next, four parameters for the DRC processing, a compression starting point in the low density side, a compression rate in the low density side, a compression starting point in the high density side, and a compression rate in the high density side are input in the DRC circuit 2113f (Step S2305). This input is performed by the changing unit 2510 or for the automatic selection performed with an output value from each analysis circuit or with a default parameter stored in the main memory 2109.

Subsequently, a density value of an original image is converted on the basis of a density value conversion

curve  $F()$  as shown in Fig. 28, for example (Step S2306). In this diagram,  $F()$  depends upon a compression starting point in the low density side, a compression rate in the low density side, a compression starting point in the high density side, and a compression rate of the high density side, and the compression rate in the low density side is equal to a slope of a straight line  $a$ ; for example, if the compression rate is 0.3, the slope is 0.3. In addition, a slope of the straight line  $c$  is equal to a compression rate in the high density side. Characters low  $v$  indicates the compression starting point in the low density side and characters high  $v$  indicates the compression starting point in the high density side. A density value is converted on the basis of this density value conversion curve  $F()$ .

Next, the high frequency component  $f_h(x, y)$  according to a slope of the density value conversion curve  $F()$  is added to an image  $f_a(x, y)$  after the density value conversion (Step S2307). A series of processing is expressed by the following formulas at a time:

$$f_c(x, y) = f_a(x, y) + \left(1 - \frac{\partial F(S_{us}(x, y))}{\partial S_{us}(x, y)}\right) \times f_h(x, y), \quad \text{----- (205)}$$

$$\text{or, } f_c(x, y) = f_a(x, y) + \left(1 - \frac{\partial F(f(x, y))}{\partial f(x, y)}\right) \times f_h(x, y)$$

$$f_a(x,y) = F(f(x,y)) \text{ ----- (206)}$$

$f_c(x, y)$  indicates a mask size for generating a smoothed image of the images d1 and d2 after the DRC processing.

5        If the processing is completed, the smoothed image and the high frequency component stored in the main memory 2209 are released following an instruction from the CPU 2208. Otherwise, processing from Step S2305 is repeated. In this processing, however, the smoothed  
10       image and high frequency component already generated and stored in the main memory 2209 are used.

Next, the control returns to the processing shown in Fig. 26 to convert the DRC-processed image by the gradation converting circuit 2114 on the basis of the  
15       gradation curve for the image display device 2111 (Step S2111) and to display the converted image on the image display device 2111 by using the control circuit 2113g. This display is shown in 2502 in Fig. 29 (Step S2211). In this diagram, triangles indicate compression density  
20       starting points in the low density side and cross marks indicate compression density starting points in the high density side. When using a color monitor, the starting point density values are changed in red or blue. At the same time, the density value conversion  
25       curve  $F()$  used for the DRC processing is displayed as indicated by 2501.

If the DRC-processed image is required to be

changed, parameters for the DRC processing are changed by using the changing unit 2510 (Step S2213) and processing is repeated from Step S2208 again. If the processing is terminated, the smoothed image and the high frequency component stored in the main memory 2209 are released.

Next, processing is described for a case in which a method of calculating parameters for the DRC processing according to an analysis circuit is selected in the above step S2201.

First, an analysis circuit is selected based on a predetermined code for each region. For example, parameters for the DRC processing of an image of limbs are extracted for the analysis circuit (1) and processing in Fig. 30 is performed.

The irradiation area extracting circuit 2113a receives the input image processed by the pre-process circuit 2106 via the CPU bus 2107 under the control of the CPU 2108 and extracts the irradiation area in the input image. On the other hand, the passing through deleting circuit 2113a which has received the input image replaces passing through areas outside and inside the irradiation area and a body area in contact with the passing through areas within a fixed space with 0 pixels (Step S2601). Specifically, the image is converted as follows.

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$$f1(x, y) = f(x, y) \times \prod_{x1=-d1}^{x1=d1} \prod_{y1=-d2}^{y1=d2} \text{sgn}(x+x1, y+y1) \text{ ----- (207)}$$

where  $f(x, y)$  is image data and  $f1(x, y)$  is an image as a result of deleting the passing through area and the body area in contact with the passing through area within a fixed space.  $\text{sgn}(x, y)$  is expressed by the following formula, supposing that  $\text{Th1}$  is a constant determined by an experiment and  $d1$  and  $d2$  are constants for determining a width by which a body area is deleted:

10            If  $\text{sgn}(x, y) = 0$  and  $f(x, y) \geq \text{Th1}$ ,  
                $\text{sgn}(x, y) = 1$ , etc. --- (208)

Next, a histogram (Fig. 31) for an area which has not been deleted is prepared and analysis processing is performed (Steps S2602 and S2603). Specifically, a  
 15            shape of the histogram is analyzed to extract a density value Target at a peak position in the low density side and it is assumed to be a compression starting point in the high density side. Furthermore, a compression rate in the high density side is calculated on the basis of  
 20            the following formula:

$$\text{Ch} = (\text{max} - \text{Target}) / (\text{Bodymax} - \text{Target}) \text{ ----- (209)}$$

where  $\text{max}$  is a density value corresponding to the maximum density  $\text{Sightmax}$  which can be recognized  
 25            visually after a gradation conversion as shown in Fig. 32 and  $\text{Bodymax}$  is the maximum value of an area after

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deleting the passing through area. For an image of limbs, only an area in the high density side is compressed.

In the analysis circuit (2), DRC parameters for an image of a front view of lungs are calculated following a processing flow in Fig. 33.

First, an image as a result of deleting the passing through area is obtained by performing processing with the irradiation area extracting circuit 2112 and the passing through deleting circuit 2113a (Step S2710) and the maximum value max is calculated from the image as a result of deleting the passing through area (Step S2720).

Subsequently, a profile through the maximum value is prepared (Fig. 34) (Step S2730) and the minimum value min of a depression is extracted (Step S2740). Then, a compression starting point dl in the low density side is calculated with the following formula (Step S2750):

$$dl = \min + (\max - \min)/2 \text{ ----- (210)}$$

For a front view of an arm, only an area in the low density side is compressed and a fixed value is used as a compression rate.

Analysis circuits (3) to (n) are used for analyzing other regions.

Next, DRC processing is performed by using the DRC circuit 2113f (Step S2208). In this processing, for a

parameter in the density side whose area is not compressed, a compression rate is set to 1 and the minimum value of the input image is used for the low density side and the maximum value of the input image is for the high density side as a compression density starting points.

A description of Steps S2210 and after is omitted since it is the same as for a manual input with the changing unit 2510.

10       The processing which has been described in the above embodiments (for example, shown in Fig. 1) can be applied to processing with the density value converting circuit 2113.

[Other embodiments]

15       The above embodiments can be realized in both hardware and software constitutions. In addition, the processing can be performed by running a program for executing processing of the above flowchart using a computer system formed by the above memory such as the main memory and other devices.

20       As a storage medium for storing the program, a semiconductor memory such as a ROM or RAM, an optical disk, an optical magnetic disk, or a magnetic storage medium can be used, and a CD-ROM, an FD, a magnetic card, a magnetic tape, or a non-volatile memory card

25       can be used for them.

It is apparent that the above embodiments and

equivalent functions can be performed and equivalent effects be obtained even if an operating system or the like running on the computer performs partially or entirely processing or if a program code read from a storage medium is written into an extended function board inserted in a computer or into a memory in an extended function unit connected to a computer and then a CPU or the like in the extended function board or the extended function unit performs partially or entirely processing on the basis of an instruction of the program code, so that these cases are included in the present invention.

Although the present invention has been described in its preferred form with a certain degree of particularity, many apparently widely different embodiments of the invention can be made without departing from the spirit and the scope thereof. It is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.